DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

MP 69-6

U. S. LAKE SURVEY
CORPS OF ENGINEERS

U. S. LAKE SURVEY

MISCELLANEOUS PAPER 69-6

THE ZEISS APPARATUS FOR CROSSING WATER SPANS IN PRECISE LEVELING

by

Ralph Moore Berry

October 1969

DEPARTMENT OF THE ARMY
LAKE SURVEY DISTRICT, CORPS OF ENGINEERS
630 Federal Building and U. S. Courthouse, Detroit, Michigan 48226

THE ZEISS APPARATUS FOR
CROSSING WATER SPANS IN PRECISE LEVELING

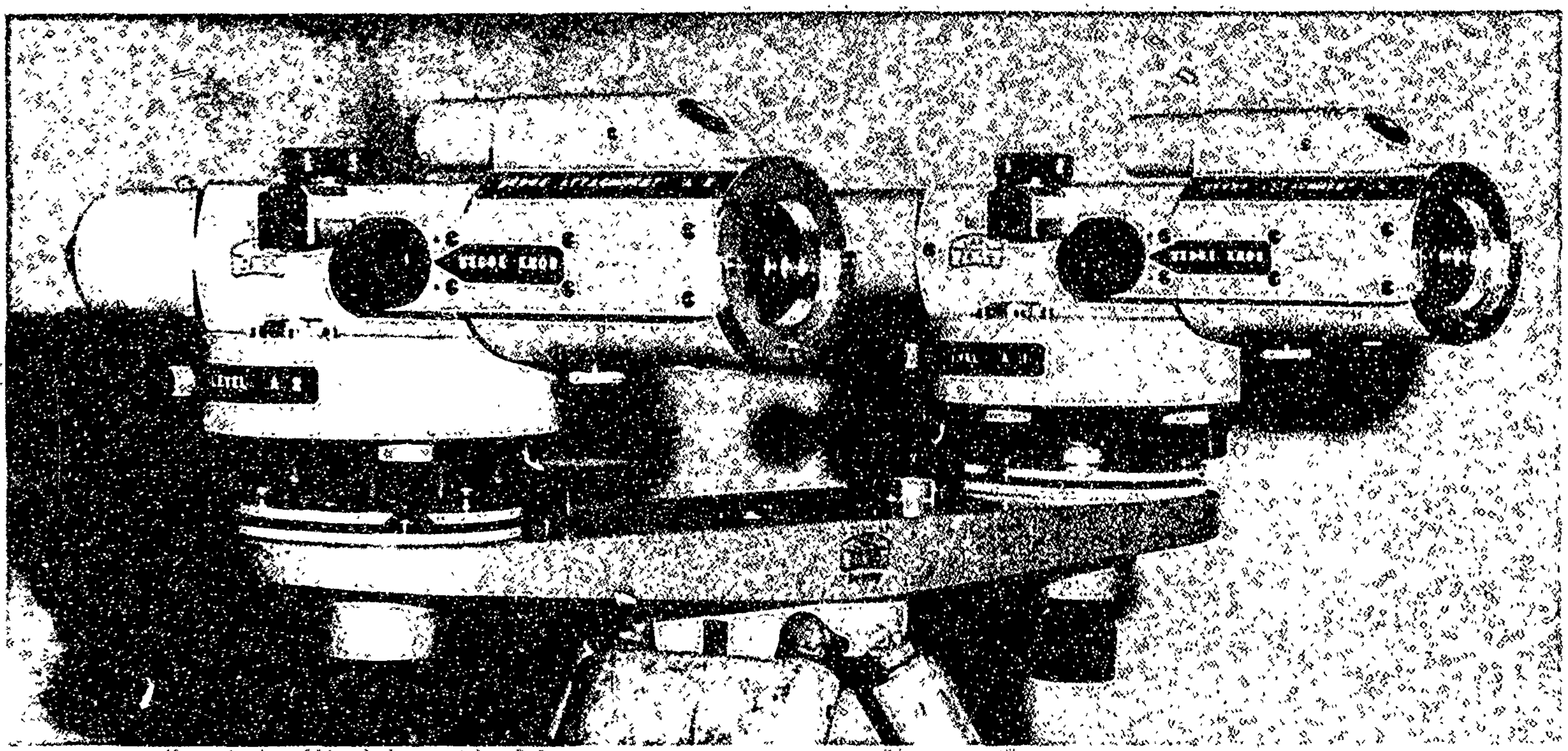
by

Ralph Moore Berry F.ASCE

Descriptors: Vertical Control - Leveling - Surveying - Water Crossing - Geodesy - Great Lakes

U. S. Lake Survey

October 1969



ZEISS "VALLEY CROSSING" EQUIPMENT

CONTENTS

LIST OF ILLUSTRATIONS

THE ZEISS APPARATUS FOR

CROSSING WATER SPANS IN PRECISE LEVELING

by

Ralph Moore Berry F.ASCE

Geodetic Consultant
Hydrographic Branch
Lake Survey District,
Corps of Engineers
Detroit, Michigan

INTRODUCTION

In connection with its program of levels of high precision along the shores of the Great Lakes and their connecting waters[1], the U. S. Lake Survey must make connections between Lake Survey lines and similar level lines established along the Canadian shores by the Geodetic Survey of Canada. These connections are necessarily made over comparatively wide water spans such as the St. Lawrence River, Detroit River, etc. where suitable rigid bridges are not available and the span is considerably greater than the maximum tolerable sight distance for standard leveling procedures.

Similar situations have been encountered frequently in the past during the process of control leveling (e.g. by the U.S. Coast and Geodetic Survey) for which special "water crossing" techniques were developed. These techniques were applicable to the older procedures where leveling was accomplished through the

[1]Feldscher, C. B. and Berry, R. M., The Use of Geopotential Heights for Great Lakes Vertical Datum, U. S. Lake Survey, Miscellaneous paper 68-6, p. 18, Detroit, 1968.

use of "spirit" levels in which the attitude of the line of sight was set ("leveled", or the bubble centered) by use of a fine vertical slow-motion "tilting screw" with a micrometer calibration. A short description of a version of the spirit-level technique for water-crossing is quoted from the instructions of the U. S. Coast and Geodetic Survey[2]:

> "The general scheme of this method of observing is that simultaneous reciprocal observations are made at each of two points, one on each side of the river. Instead of moving a single target into the line of sight, two targets are set on each rod, one above and the other below that point on the rod which is crossed by the middle horizontal wire when the bubble is centered. The graduated head of the micrometer screw is read with the telescope in each of three positions: First, with the middle horizontal wire bisecting the top target; second, with the telescope level (bubble centered); and third with the middle horizontal wire bisecting the bottom target. The reading on the rod given by the line of sight when the telescope is level can be determined, for the distance from this point to the two targets will be proportional to the corresponding differences in the readings on the micrometer head."

---

[2]Rappleye, Howard S., Manual of Geodetic Leveling, U. S. Coast and Geodetic Survey Special Publication No. 239, Washington, D. C., 1948, p. 51.

The recently-developed Lake Survey techniques for levels of high precision[3] involve the use of an "automatic" level instrument (Zeiss Ni 2 with plane-parallel plate micrometer, Fig. 1). This instrument has no spirit bubble to control the line of sight, but, instead, depends on a gravity-controlled "compensator" to set the line of sight. Details of the theory of this instrument, and the action of its compensator have been discussed by Karren[4]. There is no tilting screw involved and, hence, the spirit-level technique of water-crossing is not applicable. The new technique, however, by use of a "Rotary Wedge" (Fig. 2) attachment to the level[5], retains the same principle of setting on a pair of targets on the opposite shore, with the line of sight being tilted under carefully-controlled conditions. The principal variations are:

a. Use of a rotating optical wedge to control tilt of line of sight.

b. Use of two instruments, set in "reciprocal collimation" to compensate for effects of imperfection in vertical adjustment of line of sight.

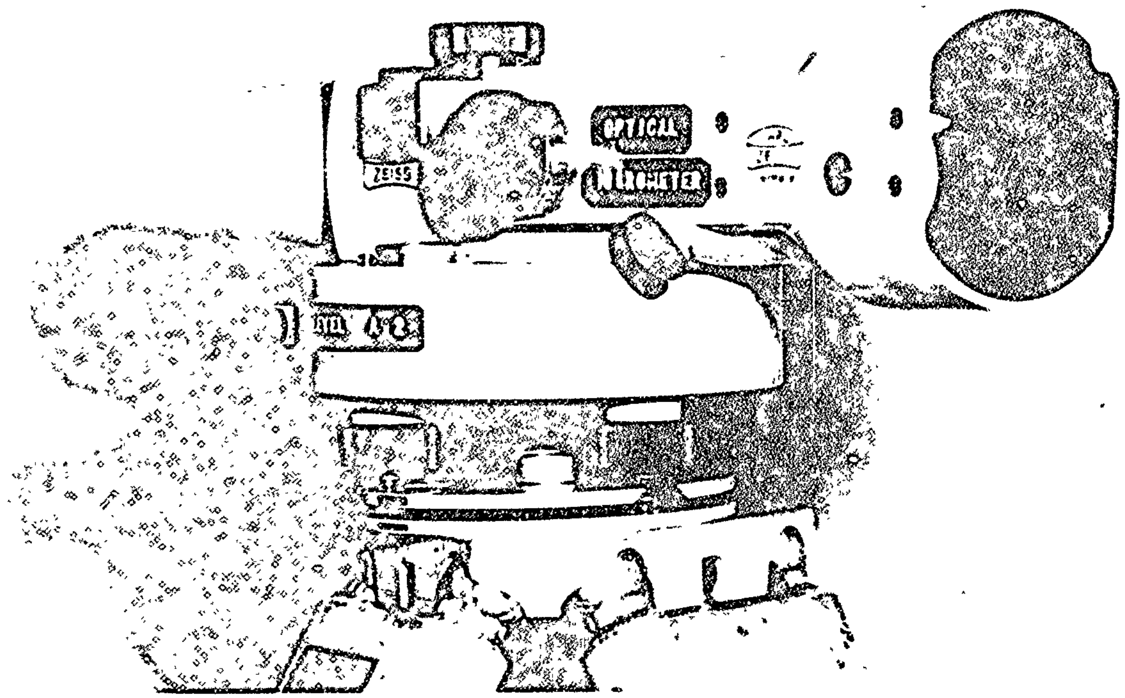
The rotating wedge consists essentially of a slightly deviating prism, cut to circular outline, and arranged in a mount so that it can be rotated about an axis parallel to the optical axis of the level, when mounted in front of the objective (Fig. 3).

---

[3]Berry, Ralph Moore, Experimental Techniques for Levels of High Precision, Using the Zeiss Ni 2 Automatic Level, U. S. Lake Survey, Miscellaneous Paper 69-4, Detroit, 1969.

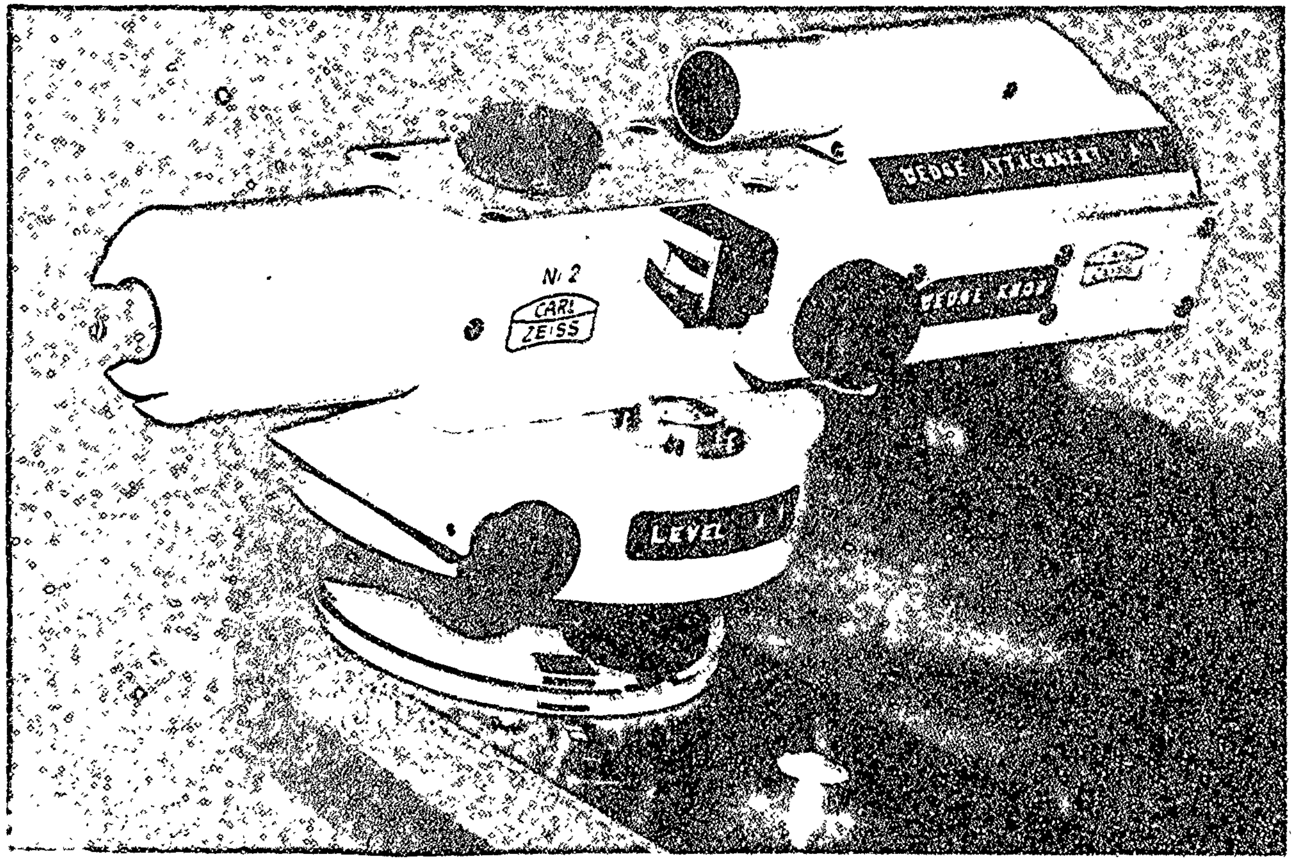
[4]Karren, Robert J., Recent Studies of Leveling Instrumentation and Adjustment, SURVEYING AND MAPPING, Vol. XXIV, No. 3, 1964.

[5]Drodofsky, Martin, Leveling Across Wide Rivers with the Zeiss Level Ni 2, ZEITSCHRIFT FUR VERMESSUNGSWESEN, 85. Jahrgang 1960, Heft 7, Stuttgart.



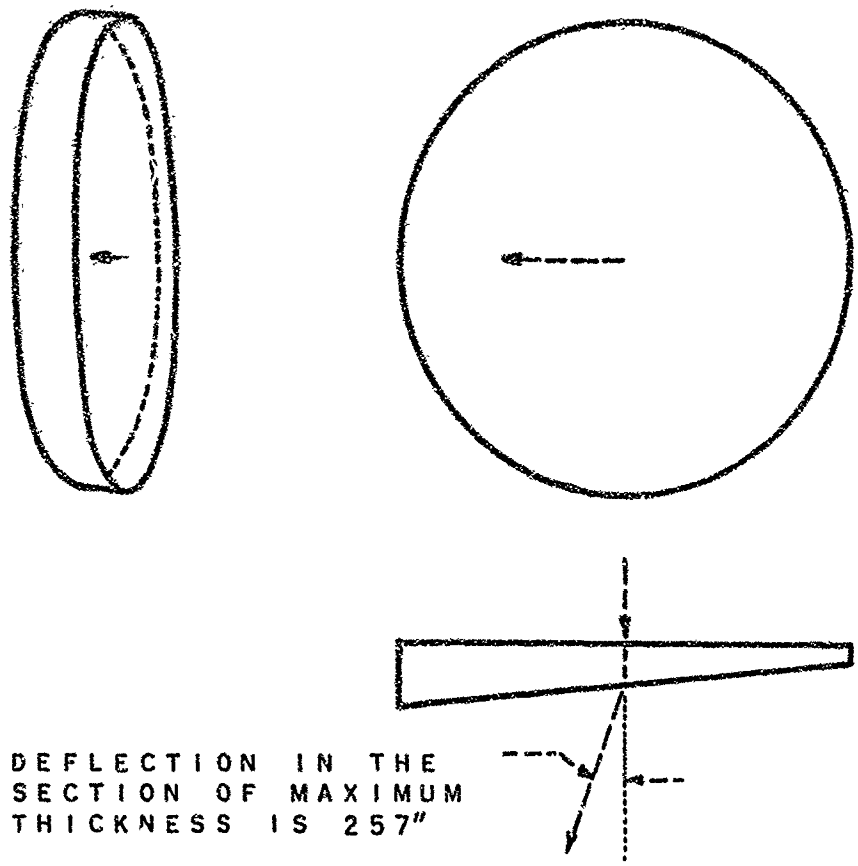
ZEISS Ni2 AUTOMATIC LEVEL WITH OPTICAL MICROMETER

Figure 1



ZEISS Ni2 LEVEL WITH ROTARY WEDGE ATTACHMENT

Figure 2



ROTATING OPTICAL WEDGE

Figure 3

An attached graduated optical scale provides an indication of the position to which it is rotated. This is similar in principle to the rotating wedge mounted in front of the objective of some precise levels, to provide a sensitive means of adjusting the inclination of the line of sight.

The wedge deflects the line of sight by a small angle (257 seconds) which deflection is in a direction perpendicular to the line of intersection of its two main faces. As indicated above, this line of intersection (or "edge") does not exist physically since the prism is cut to a circular shape, of about the same diameter as the telescope objective and the edge is thus cut away.

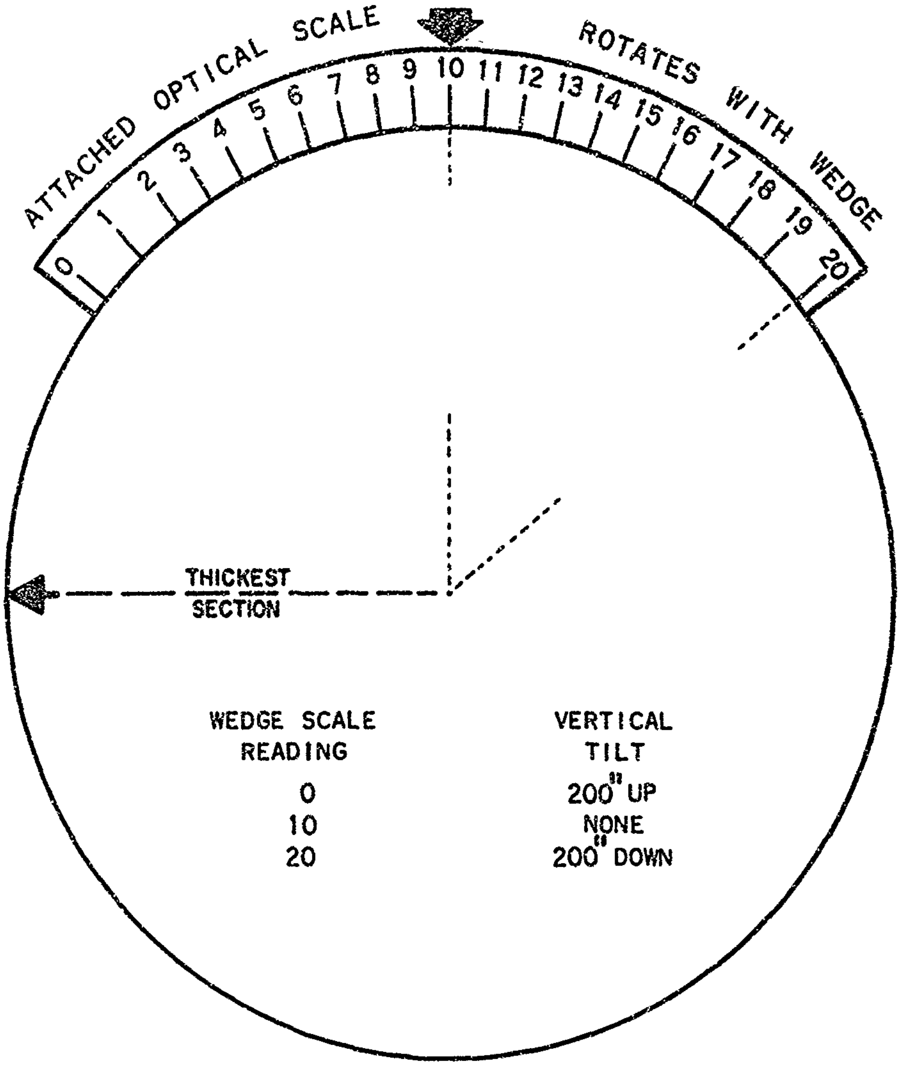
If the wedge is rotated so that its theoretical "edge" is vertical, the line of its thickest section will be horizontal, the deflection will be entirely in the horizontal plane, and the <u>vertical</u> attitude of the line of sight, as set by the compensator, will not be changed. It will merely be deflected horizontally with no effect on its vertical reading.

If, however, the wedge be rotated to some other position, the line of sight will be deflected, either up or down, at some angle with the horizontal. This deflection can be resolved into two components, a vertical tilt which is proportional to the sine of the rotation angle, and a horizontal deflection which is proportional to the cosine of the rotation angle. The wedge is designed to give a total deflection of 04'17" (257"), and its range of rotation is $51^{o}06'$ above or below the horizontal. With this maximum rotation the line of sight has a vertical tilt of $3^{o}20'$ (200") above or below the compensated line of sight. Rotation of the wedge through its limits then provides a smoothly

variable change of the vertical attitude of the line of sight through a range of 400 seconds. By thus rotating the wedge, the line of sight can be accurately set to a pair of targets, of known vertical separation and relation to an adjacent bench mark, one above and one below the compensated line of sight. Graduations on an attached optical scale (Fig. 4), in units of equal increments of sine of the rotation angle, permit reading of the vertical tilts, and their relation to the compensated line of sight, with a precision of 0.2 second of arc. The position of the intercept of the compensated line of sight, between the two targets on the opposite shore, is calculated by simple proportion. To avoid difficulty with algebraic signs, the unrotated position of the wedge (no vertical tilt) is numbered "10" with the position of maximum upward tilt graduated "0" and the position of maximum downward tilt graduated "20".

The above procedure gives a precise determination of the intercept of the compensated line of sight between the targets, but its accuracy is directly influenced by the adjustment condition of the instrument and the corresponding deviation of the line of sight from a true "level" attitude. This problem is essentially solved by use of the principle of "Reciprocal Collimation," involving use of two Ni 2 levels mounted on the same tripod, through use of a base plate with provision for attachment of the two levels.

The two levels, attached to a Base Plate mounted on the head of the tripod(on which they remain set for the entire set of water-crossing observations) are turned to face each other, objective to



OPTICAL WEDGE SCALE

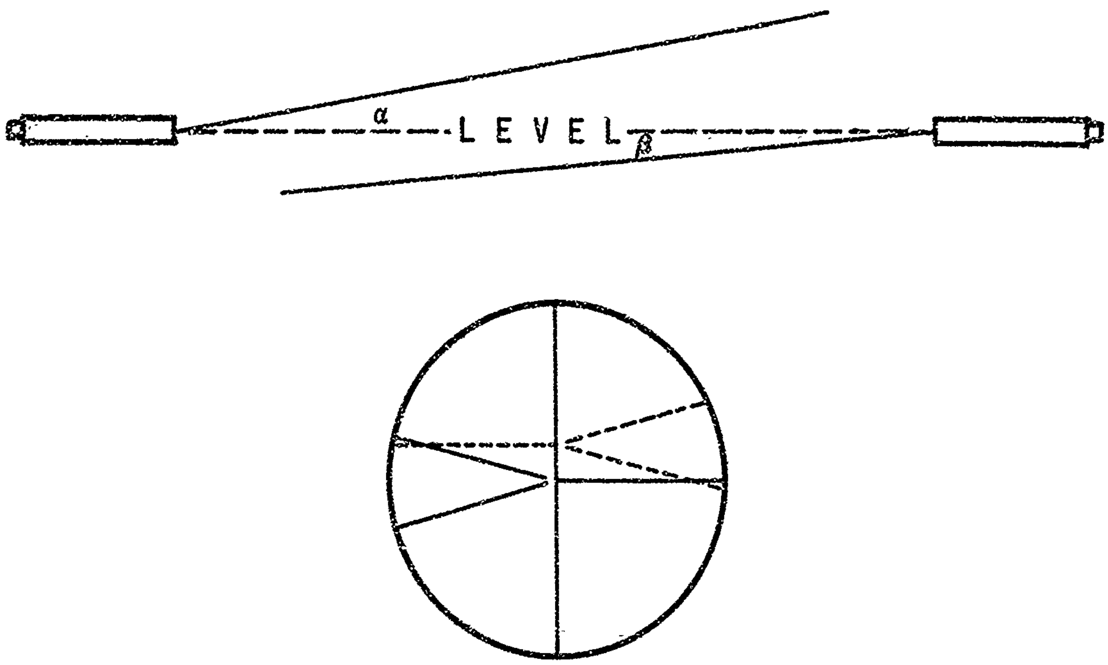
Figure 4

objective (Fig. 5). One instrument is focused to infinity and the other one focused so that the reticle lines of the first instrument are seen sharply in the field of view of the second instrument. The wedge on the first instrument is set to read "10.00" precisely, thus introducing no tilt in the line of sight (Because of adjustment error, this does not mean that the line of sight is level. It merely means that the wedge is not introducing any tilt.). When viewing this in the field of view of the second instrument, the horizontal reticle line of the first instrument will usually appear somewhat above or below the horizontal reticle line of the second instrument because the two instruments will not generally have the same adjustment error. The two instruments are then set in Reciprocal Collimation by rotating the wedge of the second instrument until the two horizontal reticle lines are in coincidence (Fig. 6). The reading of the wedge scale of the second instrument is noted, and this position becomes the reference from which its intercept between the two distant targets is computed.

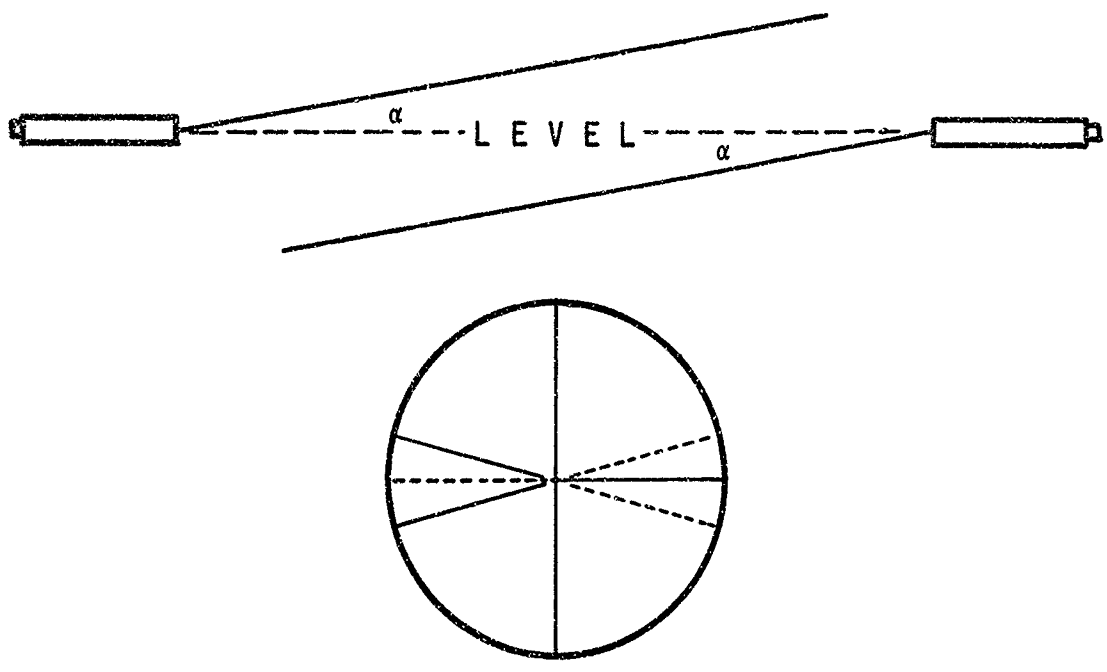
By this Reciprocal Collimation, the lines of sight of the two instruments are set parallel, not level, but with the same (undetermined) inclination, one above "level" and the other quite accurately below "level" by the same amount. When turned toward the targets, the computed mean intercept of the lines of sight of the two instruments (thus collimated) between the two targets is essentially free from error of adjustment, even though the two instruments may be at slightly different elevations (due to base-screw positions, etc.) It is however, still influenced by the very considerable effects of refraction and earth curvature. These latter effects are essentially cancelled by

PAIR OF ZEISS Ni2 LEVELS IN POSITION FOR RECIPROCAL COLLIMATION

Figure 5



BEFORE RECIPROCAL COLLIMATION
Level Lines of Reticles Not Coincident
LINES OF SIGHT NOT PARALLEL



AFTER RECIPROCAL COLLIMATION
Level Lines of Reticles Set Coincident
LINES OF SIGHT PARALLEL

Figure 6

making simultaneous observations with another set of Ni 2 levels (four, in all) set on the opposite shore. If conditions are favorable, refraction and curvature effects for this other determination will be equal in magnitude but opposite in sign, so the mean determination from the two simultaneous observations in opposite directions will be essentially free of error due to these causes.

To obtain accurate results, all precautions against error must be taken, and the quite detailed procedures must be strictly followed. A detailed description of the instruments, the precautions and reconnaissance procedures, and detailed instructions for observations are set forth on the following pages.

ZEISS VALLEY CROSSING EQUIPMENT

*1. VALLEY CROSSING EQUIPMENT, Purpose:

The Carl Zeiss (West Germany) equipment, listed as the "Valley Crossing Equipment," is a set of accessories intended to be used with a pair of Zeiss Ni 2 "automatic" levels. It facilitates the determination of differences of elevation between widely separate points, as across a river, where determination by standard leveling procedures using balanced sight lengths is precluded by physical conditions. Since the situation seldom arises except where water prevents the use of intermediate "turning points," the terminology "water crossing" is usually applied to this technique.

2. VALLEY CROSSING EQUIPMENT, List of items:

As supplied, one set of equipment consists of:

2 Rotary Wedge Attachments

1 Base Plate

1 Tribrach

1 Target Column

2 Targets

1 Auxiliary Level Scale (half-centimeter(semi-centimeter), E-pattern graduations)

1 Plane Mirror Auto-Collimation Attachment

1 Illumination Ocular Prism

---

*Since the following material constitutes the complete instructions, independent of the foregoing INTRODUCTION, the series of reference numbers begins at this paragraph.

3. ADDITIONAL EQUIPMENT:

Additional required equipment for a single set includes:

2 Zeiss Ni 2 automatic levels, with tripods, designated and marked as "No. 1" and "No. 2"

1 Level rod, precise, with half-centimeter (semi-centimeter) graduations

1 Plane-parallel micrometer for Ni 2 level, compatible with rod graduation

4. ROTARY WEDGE ATTACHMENT, Purpose:

The Rotary Wedge Attachment slips over the objective end of the Ni 2 level and provides an optical means of changing the vertical inclination of the line of sight of the level through a small accurately-controlled range. It is similar to the rotatable prism placed in front of the objective of some precise level instruments for the purpose of providing a precise means of adjustment of the vertical inclination of the line of sight. As used with the Valley Crossing Equipment, however, it is a means of setting and reading the attitude of the line of sight.

5. ROTARY WEDGE ATTACHMENT, Description:

The Rotary Wedge Attachment provides the basis for the system of operation and must be made with the highest quality of craftsmanship and precision. It consists of a freely-rotatable prism attached to an optical scale which can be read by the observer from his position at the ocular end of the level. As the prism (wedge) is rotated in front of the objective of the level, through a linkage connected to the Wedge Knob, the line of sight, as

defined by the horizontal ("Level") line of the reticle, is tilted slowly through a vertical range of approximately six and a half minutes of arc. The attached optical scale is non-linear in graduation but the graduation intervals indicate equal vertical angular changes in the inclination of the line of sight. The prism has a rotation range of approximately 102° and the optical scale range is 20 main units to cover this rotation. Each main scale unit is subdivided into ten sub-units. The space between each sub-unit is wide enough to permit easy estimation of tenths of a sub-unit. The optical scale can thus be read to an estimated hundredth of a main unit. The line of sight is tilted vertically two seconds for each sub-unit of the optical scale. Thus the vertical attitude of the line of sight is estimated to 0.2 second . When the optical scale is set to read precisely 10.0 units, no vertical tilt is being introduced by the prism. Thus the range of tilt is approximately 200 seconds above (scale reading 0.00) to 200 seconds below (scale reading 20.00) the untilted line of sight. The readings of the optical scale are assumed to be in a linear relationship to actual linear displacement at the rod or target, and are used for proportional computation of the relationship of the untilted line of sight.

6. ROTARY WEDGE ATTACHMENT, Rotation:

Rotation of the prism is accomplished by turning the Wedge Setting Knob. When the attachment is in place on the objective end of the telescope on the Ni 2 level, rotation of the wedge

effects a change in the vertical attitude of the line of sight. The optical scale is correspondingly rotated, with the readings changing by an amount that is proportional to the angle of tilt. The Wedge Knob is provided with a selective coarse and fine motion, similar to the objective focusing device on the level. The coarse mode is available for the entire range of the rotation. When in coarse mode, the knob is slightly hard to turn. Mode is shifted from coarse to fine by merely reversing the direction in which the knob is being turned. The knob is much easier to turn when in fine mode. The fine mode is "in gear" for only about 0.5 to 1.0 scale unit (depending on which part of the optical scale is being used) after which it reverts to coarse mode. Setting can be made much more accurately with the device in fine mode, and <u>all final</u> settings must be so made.

7. BASE PLATE, Description:

The Base Plate is an elongated metal casting which can be screwed onto the head of a standard European level or theodolite tripod. It is provided with appropriate clamp screws so that two Zeiss Ni 2 levels can be mounted on it, providing a means for mounting the two instruments adjacent on the same tripod and at nearly the same elevation. Red index marks have been provided to indicate the placement of the two Ni 2 levels, designated "No. 1" and "No. 2."

8. BASE PLATE, Set-up:

When the tripod and Base Plate are set up at a station, the Base Plate should be nearly level as indicated by the circular level mounted at its center. This will assure that the elevations

of the lines of sight of the two Ni 2 levels will be nearly equal. The Base Plate should be oriented with its long axis approximately perpendicular to the line of sight to the opposite target and with the indexed position of Instrument No. 1 on the left before leveling it. There are no leveling screws or similar device on the Base Plate, and the leveling must be effected by changing the positions of the tripod feet in the ground or by varying the lengths of the tripod extension legs. Leveling is not critical but the bubble should be inside the ring. The set-up should be very firm in the ground as it will be assumed not to move during the extended observations.

9. BASE PLATE, Placement of Ni 2 Levels:

The Ni 2 levels are attached to the Base Plate by use of the clamp screws similar to the direct attachment to a tripod head. The two levels should be appropriately located in the positions marked "No. 1" and "No. 2," and the red index marks on the leveling base of the levels should be aligned with the numbered index marks on the Base Plate. This will place one leveling screw of each instrument approximately on the long axis of the Base Plate, the other two screws then being aligned perpendicular to the long axis. Immediately after setting up, the three leveling screws on each instrument should be set to the mid-position of their range of movement. This is accomplished by turning each leveling knob until its top edge is aligned with the indexing ring marked on the dust skirt. This will minimize difference of elevation of the two instruments. After this setting is made all subsequent leveling adjustments of each instrument are made by

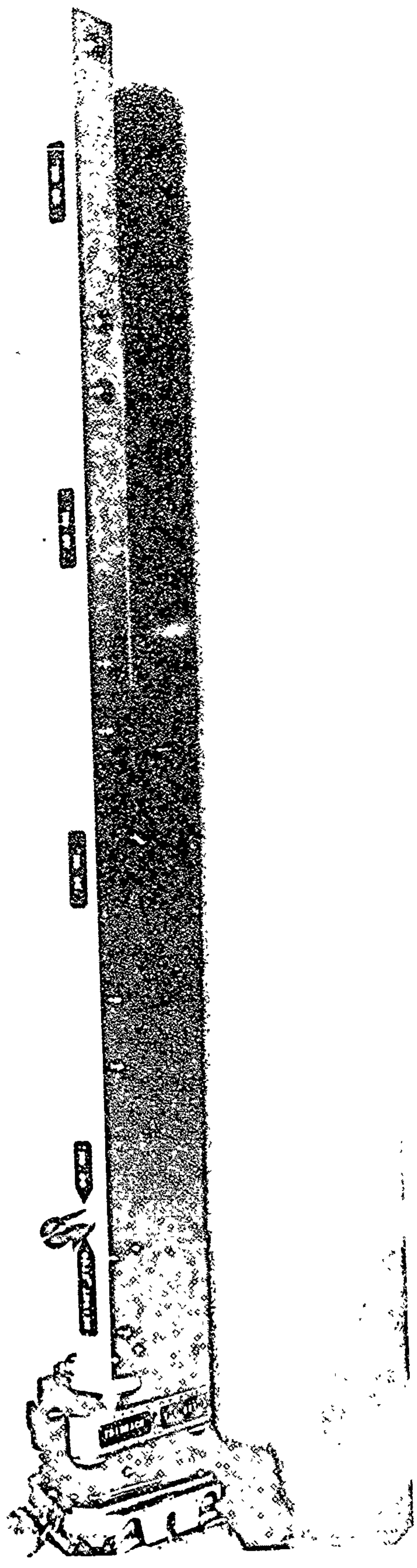
using only the two leveling screws which are aligned perpendicular to the long axis of the Base Plate. On each instrument the leveling screw that is on the long axis of the Base Plate is not touched again during the entire observation series.

10. TRIBRACH, Description:

The Tribrach is essentially a typical standard German, separate, three-screw, leveling base intended to be used with any surveying instrument provided with the standard stub for mounting. In this application, it provides a means for mounting the Target Column on a standard European tripod, and setting it vertical by use of the leveling screws.

11. TARGET COLUMN, Description:

The Target Column is a member of "channel" section, with a standard German surveying instrument stub by means of which it can be secured in a vertical attitude in the Tribrach. A circular level bubble at the foot of the Column provides a reference for setting the Column precisely vertical by use of the leveling screws in the Tribrach. It contains four pairs of precisely spaced studs on which the two Targets can be racked at vertical spacings of 40, 80, 120 semi-centimeters (Fig. 7). A "Height Stud" is set horizontally near the base of the Column, terminating in a spherical knob, the top of which is at precisely the same elevation as the target center defined by the lowest pair of studs. The top of the knob is therefore the reference point by means of which the target pair is related to an adjacent bench ma k.



TARGET COLUMN

Figure 7

12. TARGET, Description:

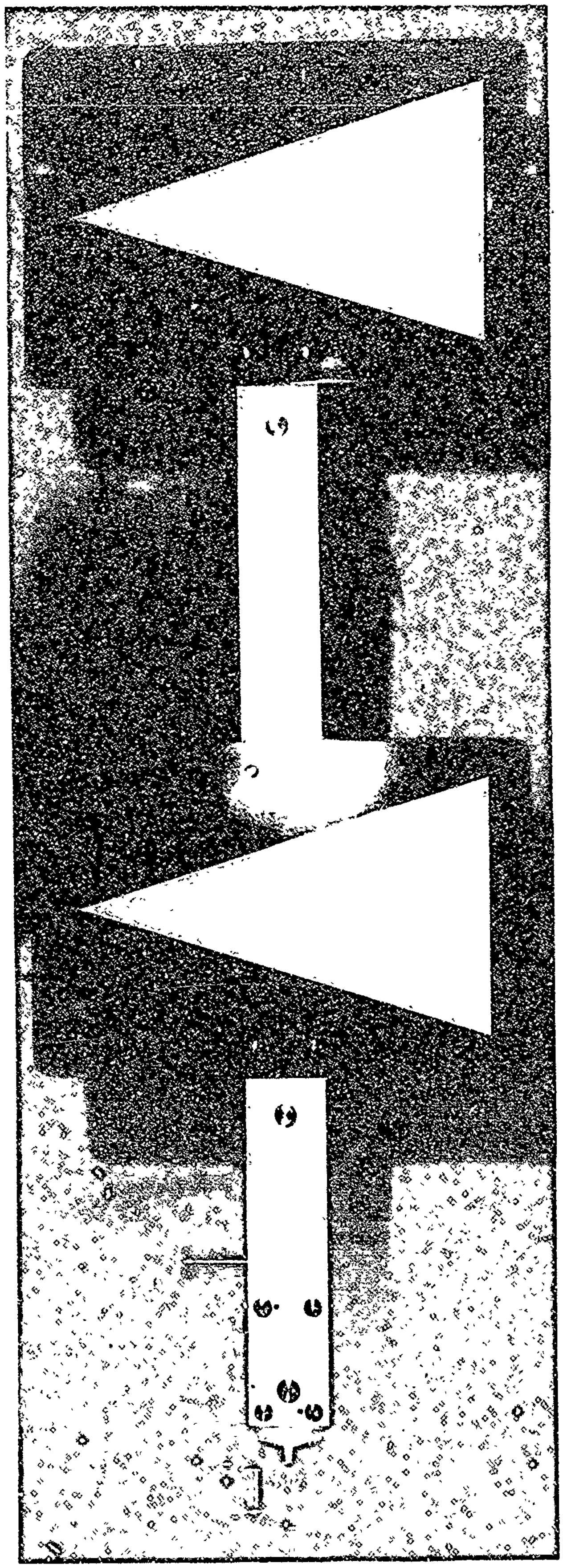
Two metal target plates (20 x 30 cm) are provided with the set. Each plate is black with white horizontal triangular target painted on it. This pattern is very well adapted to the setting of the horizontal level line of the reticle at a considerable distance.

13. TARGET, Placement:

The Target Column, (Par. 11), is provided with four sets of studs on its front face, each pair constituting a means of mounting a Target. The horizontal centerlines of the Targets are thus located on the Target Column at 0, 40, 80, or 120 semi-centimeters above the Height Stud. The placement of the Targets is at the observers discretion (Fig. 8). In use, they must be placed so that one Target is above the instruments "level" (untilted) line of sight and one is below. The lower target is not necessarily set in the lowest position (Zero distance above Height Stud). The positions of the Targets must be noted and recorded (par. 21d).

14. AUXILIARY LEVEL SCALE, Description:

The Auxiliary Level Scale is a short separate wooden level rod, 0.6 meters long, graduated in semi-centimeter divisions, in the "checkerboard" or "E-Pattern" style. It can be considered to be graduated to hundredths of semi-meters. The graduations are grouped and numbered in sets of ten divisions. The units are blocks of alternate black and white, similar to the pattern of the standard Coast and Geodetic Survey precise level rod, except



TARGETS IN PLACE

Figure 8

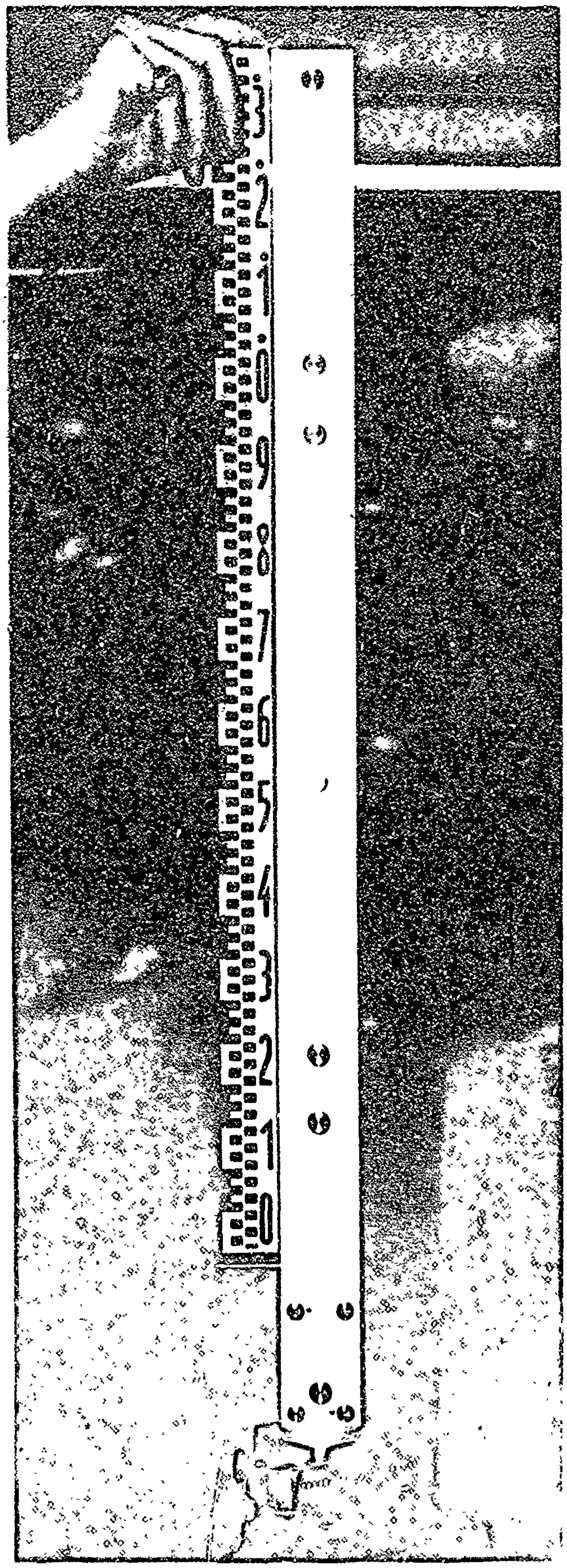
that the units are semi-centimeters instead of centimeters. The first ten groups of divisions are numbered from 0 through 9, which should be read as tenths of a half-meter with a leading zero preceding the decimal point, thus: 0.1, 0.7, 0.9, etc. The second series consists of only four groups of divisions, numbered from 0 through 3 but with a large dot over each number to indicate that, in reading, it should be preceded by "1.," thus: 1.0, 1.1, 1.2, 1.3. Each block within a group is a hundredth of a half-meter unit, and is read as the second decimal place.

15. AUXILIARY LEVEL SCALE, Use:

The Auxiliary Level Scale is used in the determination of the difference in elevation between the bench mark and the Height Stud on the Target Column adjacent to it. (NOT the Target Column at the opposite station of the Crossing) In use, the Auxiliary Target Scale is held (by hand) vertically against the Target Column with its zero end resting on the top of the knob of the Height Stud (Fig. 9). In this use it serves as a precise level rod, and reading is made with the Ni 2 level with the plane-parallel plate micromet :. The reason for use of this special scale is that it would be very awkward to hold a standard precise level rod on the Height Stud without disturbing the set-up, as the stud will be about 1 1/2 meters above the ground.

16. ASSEMBLY, Instrument Outfit:

The Instrument Outfit consists of two Ni 2 levels, mounted on the Base Plate, with Rotary Wedge Attachment on each, screwed onto a standard tripod. This outfit is used at the "Instrument Station."



AUXILIARY LEVEL SCALE

Figure 9

17. ASSEMBLY, Target Outfit:

The Target Outfit consists of two Targets, attached to the Target Column which is set into the Tribrach. The Tribrach is screwed onto a standard tripod. The Auxiliary Level Scale should be available. This outfit is used at the "Target Station."

PRELIMINARY PREPARATION

18. BENCH MARKS:

As stated in par. 1, the primary purpose of the Valley Crossing Equipment is to make an accurate determination of the difference in elevation across comparatively long spans, as across a river, where the conventional techniques of "levels" cannot be used. In practice, a bench mark, which may be either permanent or temporary (but more secure than an ordinary "turning point") is set on each side of the span, in such situation that the "crossing" operation will determine the difference in elevation between them. Bench marks must be so placed that the relationships to the equipment, as stated in the following paragraph, will be observed.

19. EQUIPMENT, Distribution:

In use, the Instrument Outfit is placed on one side of the span, and the Target Outfit on the other side. Careful reconnaissance should be made in order to accomplish the most practicable compliance with the following:

a. Line of sight crossing span at approximately right angles in order to minimize length of span.

b. Selection of location of crossing at site with minimal span consistent with location of level line and general vicinity of required crossing.

c. Location accessible to main lines of levels being connected or extended, to minimize length of connecting lines.

d. Location at highest practicable clearance over land or water. Avoid near-grazing line of sight.

e. Terrain characteristics similar at both stations, e.g., avoid steep bank on one side and gentle beach on other.

f. Target Outfit when set up must have one target above and other target below "level" (reciprocal collimated) line of sight of both levels at Instrument Station.

g. Bench mark adjacent to Instrument Station must be between five and fifty meters from instruments and at such elevation that both instruments can read a standard precise level rod held on it.

h. Bench mark adjacent to Target Station should be at such position and elevation that the Auxiliary Level Scale held on the Height Stud and a standard precise level rod held on the bench mark can be observed from a single level set-up equidistant from the points and between five and fifty meters distant. This requirement may be overlooked if necessary in order to comply with other requirements listed above.

i. Reciprocal lines adjacent and at nearly same elevation and length, as stated in par. 20.

20. SIMULTANEOUS RECIPROCAL OBSERVATIONS:

The theoretical basis for this system of observations assumes that errors due to the effects of refraction and earth

curvature are compensated by observing the difference of elevation in both directions. If only one set of equipment (two levels, one target outfit) is available, equipment must be interchanged across the span and observations made in the opposite direction. It must then be assumed that refraction conditions did not change in the interim, but this cannot be safely assumed. Better practice is to use two complete sets of equipment and make simultaneous observations in both directions. (cf. par. 30) This involves setting an Instrument Outfit on each end of the span, observing to its own Target Outfit on the opposite side. There is no difference in the actual observing procedure followed. Care must be taken to avoid confusion in recording and computing. The main source of confusion lies in the fact that the difference in elevation between the bench mark and the Target Outfit, adjacent to the Instrument Outfit, though determined by the observer at the Instrument Outfit, are not part of his determination of difference across the span. He will use only the similar difference determined by the observer on the OPPOSITE side. For the assumption of equal refraction to be valid, the two observed lines should be adjacent, should not differ in elevation by more than approximately one meter, and should not differ in length by more than approximately a half-meter.

21. PRELIMINARY OPERATIONS:

Prior to actual observations, the following preliminary operations should be completed:

a. Reconnoiter for station sites (par. 19)

b. Establish a bench mark adjacent to each set-up (par. 18). A single bench mark on each side will suffice for both the Instrument Station and the adjacent reciprocal Target Station on the same side.

c. Set up Instruments and Targets on each side.

d. Set Targets to proper positions on Target Column (each set). This must be done carefully to insure that the pair of targets will properly bracket the "level" line of sight from the opposite instrument pair (par. 13). Enter target positions (T,t) on the Target Column (0, 40, 80, 120 scm) in the appropriate set of field notes. This will usually mean that this must be communicated by radio to the Instrument Station on the opposite side. The position of the lower target is designated "T", and the position of the upper target is the quantity designated "t". The distance between them (t-T) is the quantity "D".

e. Run closed line of levels on each side between the bench mark and the Height Stud (par. 11) of the adjacent Target Outfit. Even if the difference of elevation can be observed with a single set-up, it must be "closed" by changing the set-up and observing the difference a second time. A precise level rod is observed at the bench mark and the Auxiliary Level Scale (par. 15) observed on the Height Stud. Since the two levels have already been set up on the Base Plate (item "c" above, also pars. 7, 8, and 9) at the Instrument Station, it will be helpful to have an extra level tripod available for use in determining this difference by merely removing one Ni 2 level from the Base Plate instead of completely breaking down the Instrument set-up.

The plane-parallel plate micrometer should be used in this operation. This difference in elevation, between the Height Stud of the Target Column and the adjacent bench mark, is the quantity designated "L".

22. SET-UP, Instrument Outfit:

The set-up for the Instrument Outfit must be very secure. Observe the requirements noted in pars. 8 and 9, regarding the situation of the Base Plate and the placement of the two Ni 2 levels.

23. SET-UP, Target Outfit:

The Target Outfit must be set-up after careful reconnaissance (par. 19). The Tribrach is attached to the tripod by use of the central clamping screw. The stub of the Target Column is inserted in the socket of the Tribrach and secured and leveled (pars. 10 and 11). The two Targets are placed on the mounting studs at the spacing (par. 13) appropriate to the elevation and distance of the Instrument Station. The upper Target <u>MUST</u> be <u>ABOVE</u> the "level" (untilted) line of sight of <u>BOTH</u> levels, and the lower Target <u>MUST</u> be <u>BELOW</u> the untilted line of sight of both levels and their positions on the Target Column entered in the field notes (par. 21d).

OBSERVATIONS

24. LEVELING:

Turn both instruments <u>away</u> from the Target Station. This is indicated on the note form as position " ↓ ". Then carefully

center each circular level bubble. First, equalize the leveling screws, and subsequently use only two leveling screws on each instrument for this and subsequent levelings, as stated in par. 9.

25. RECIPROCAL COLLIMATION:

Perform the Reciprocal Collimation operations as follows:

a. Focus Instrument No. 1 to infinity by turning the focusing knob in the direction indicated by the pointers on the edge of the knob until it comes against the infinity "stop". (The setting of this stop can be adjusted by turning the screw marked with a red dot, located on the right side of the body of the instrument about 1 cm below the "Carl Zeiss" trademark). Then adjust focus of Instr. No. 2 so that, when the two instruments are directed into each other, objective to objective, the reticle lines of Instr. No. 1 are sharply seen through the eyepiece of Instr. No. 2. Both instruments will then be set at infinity focus. (In equipment presently used, Instr. No. 2 does not have an infinity focus "stop", and must be focused against Instr. No. 1).

b. Rotate the Wedge Knob on Instr. No. 1 until the optical scale is set precisely to 10.00. This must be done carefully with the Wedge Knob mechanism in fine mode (par. 6). Then, rotate the Wedge on Instr. No. 2 to bring the horizontal reticle line into precise coincidence with the image of the horizontal line of Instr. No. 1. Make the final setting by moving the Wedge Knob in a clockwise direction in fine mode. Record the reading of the optical scale on Instr. No. 2. Then move the coincidence off a small amount and reset the coincidence, but this second

time make the final setting by moving the Wedge Knob in a counterclockwise direction (but still in fine mode). Record this second reading. This pair of readings after setting the circular level bubbles constitutes a Reciprocal Collimation setting. By this operation, the vertical lines of sight of the two instruments are adjusted to a parallel situation by optical collimation. (This does not mean that they are both truly "level", but merely that they are quite precisely parallel.) In effect, by setting the optical scale of Instr. No. 1 to 10.00, the line of sight of that instrument is not deviated significantly from the attitude imposed by the adjustment situation of its compensator and reticle. The line of sight of Instr. No. 2 is then tilted into parallelism with Instr. No. 1. Thus, when the two instruments are both directed toward the Target Station, one line of sight is directed slightly above true level (adjustment of Instr. No. 1 can NEVER be PERFECT) and the other is tilted by precisely the same angle below true level. The mean determination of these two lines of sight is thus a precise measure of where a line of sight free of collimation error would intercept the space between the targets. The mean of the scale readings of Instr. No. 2 is the quantity designated "r".

26. BENCH MARK, Instrument Station Observations:

Observations must be made from the Instrument set-up to a precise level rod held on the adjacent bench mark, in order to determine the height of the Instrument Station (mean of the line of sight heights of the two levels) above the bench mark. This observation is made by use of the Rotary Wedge, by setting

the horizontal line of the reticle on each of two graduation lines on the level rod, one above and one below the "level" line of sight, with each of the two instruments. For efficient accomplishment and effective use of the fine mode of the Wedge Knob (par. 6), the following procedure is recommended:

a. Turn the instruments (from their Reciprocal Collimation positions) and point on the level rod held on the bench mark. Refocus carefully for sharp image.

B. Set optical scale of Instr. No. 1 to 20.0 by turning Wedge Knob clockwise in coarse mode (optical scale moves counter-clockwise). Setting is not critical and fine mode is not required.

c. Reverse and turn the Wedge Knob counterclockwise until the horizontal reticle line has been moved upward on the rod to a position very slightly above the first rod graduation encountered on the "main" scale. The setting motion will probably be in coarse mode.

d. Reverse and turn the Wedge Knob <u>clockwise</u> (it will now be in fine mode) and set precisely on the rod graduation. Record the rod graduation ("G") and the reading of the optical scale.

e. Continue turning the Wedge Knob in clockwise direction until the reticle line is very slightly below the rod graduation. Release fingers from the knob and take hold of it in another place. Then reverse direction of turning (to counterclockwise) and again set on the rod graduation. Record reading of optical scale. The mean of this scale reading and that obtained in "d", above, is the quantity "ℓ_1".

f. Set optical scale to a reading of 0.0 by turning the Wedge Knob counterclockwise in coarse mode. Setting is not critical and fine mode is not required.

g. Reverse and turn the Wedge Knob clockwise until the horizontal reticle line has been moved downward to a position very slightly below the first rod graduation encountered on the "main" scale. The setting motion will probably be in coarse mode.

h. Reverse and turn the Wedge Knob counterclockwise (now in fine mode) and set precisely on the rod graduation. Record the rod graduation ("g") and the reading of the optical scale.

i. Continue turning the knob in counterclockwise direction until the reticle line is very slightly above the rod graduation. Release fingers from the knob and take hold of it in another place. Then reverse direction of turning (to clockwise) and again set on the rod graduation. Record reading of optical scale. The mean of this reading and that obtained in "h", above, is the quantity "u_1".

j. Repeat steps (a) through (i), with Instr. No. 2, on the same rod graduations. The corresponding quantities "ℓ_2" and "u_2" are thus obtained.

If the above procedure is carefully and precisely followed, the range of the fine movement will be sufficiently long to permit both settings on a rod graduation to be made without reverting to the coarse mode. The fine mode is obvious to the observer because the effort required to turn the knob is significantly less. It is <u>important</u> that all <u>final</u> settings be made with the Wedge Knob in <u>fine</u> mode. It is <u>also important</u> that settings with both instruments be made on the <u>same graduations</u>, both in this set of readings and in the closing set (par. 32).

(The data obtained from this operation, combined with the data from settings of par. 25, provide the quantity "R", par. 38.) The relationships of the quantities observed in this operation are shown in Fig. 10.

27. RELEVELING:

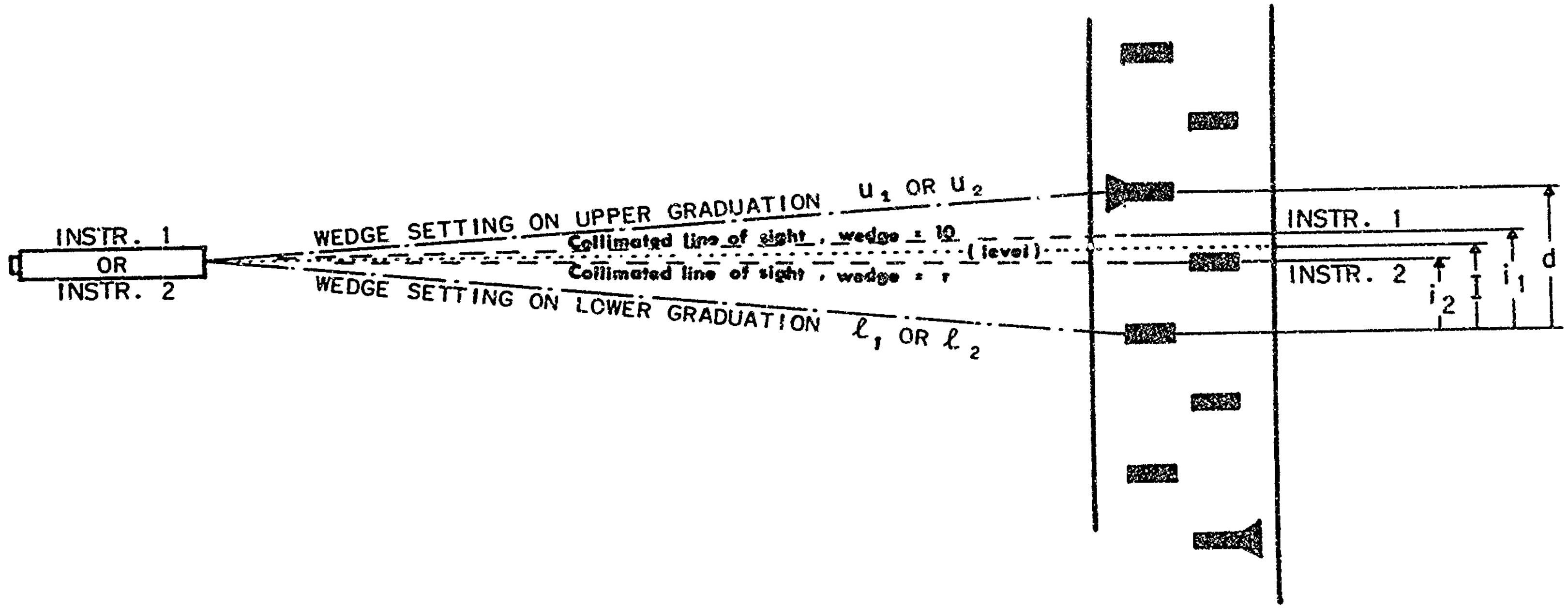
On completion of the rod readings on the bench mark, turn both instruments toward the Target Station. This is the position indicated on the field note form with " ↑ ". Then displace the circular bubbles on both instruments so that the bubbles are decentered in the direction toward the Target Station. Then carefully re-center them. This basic operation is repeated a number of times during the complete series of operations, but the instruments are alternately turned toward and away from the Target Station in successive operations. The bubble is always decentered toward the Target Station.

28. RECIPROCAL COLLIMATION, Repeat:

Repeat operations of par. 25. This procedure does not change, but is repeated a number of times during the complete series of operations.

29. TARGETS, Instrument Station Observations:

After Reciprocal Collimation, proceed to make a set of observations on the two targets on the Target Station (Pars. 10-13, 17, 19f) at the opposite end of the line. (No observations are made on the targets of the adjacent Target Outfit. They are observed only by the party at the Instrument Station at the opposite end of the line, making the reciprocal observations.) For efficiency and to eliminate confusion, the following procedure should be followed:



$$i_1 = (d)\frac{\ell_1 - 10}{\ell_1 - u_1} \qquad i_2 = (d)\frac{\ell_2 - r}{\ell_2 - u_2} \qquad I = (i_1 + i_2)/2$$

WEDGE SETTINGS ON ROD GRADUATIONS

Figure 10

With Instr. No. 1 pointed on the Target Outfit:

a. Turn Wedge Knob clockwise until the horizontal reticle line is moved very slightly below the lower target. If reticle line is already below lower target, move it to a position substantially above target before starting.

b. Reverse Wedge Knob (now in fine mode) and turn counterclockwise until the reticle line (moving upward) is set precisely on the lower target. Record optical scale reading.

c. Turn Wedge Knob counterclockwise until reticle line is raised slightly above target.

d. Release fingers from Wedge Knob and take hold of it in a different place.

e. Turn Wedge Knob clockwise, remaining in fine mode, and reset reticle line (moving downward) precisely on lower target. Record optical scale reading.

f. Make new setting in counterclockwise direction by repeating steps (a) and (b). Record reading.

g. Make new setting in clockwise direction by repeating steps (c), (d) and (e). Record reading.

h. Repeat steps (f) and (g), in sequence, until a total of ten settings has been made (and recorded) with Instr. No. 1, on the lower target. (The mean of these ten readings is the quantity "b_1".)

i. Turn Wedge Knob counterclockwise (reticle line moves upward) until the reticle line is slightly above the upper target.

j. Reverse Wedge Knob (now in fine mode) and turn clockwise until the reticle line (moving downward) is set precisely on the upper target. Record optical scale reading.

k. Turn Wedge Knob clockwise until reticle line is moved slightly below upper target.

l. Release fingers from Wedge Knob and take hold of it in a different place.

m. Turn Wedge Knob counterclockwise, remaining in fine mode, and reset reticle line (moving upward) precisely on upper target. Record optical scale reading.

n. Make new setting in clockwise direction by repeating steps (i) and (j). Record reading.

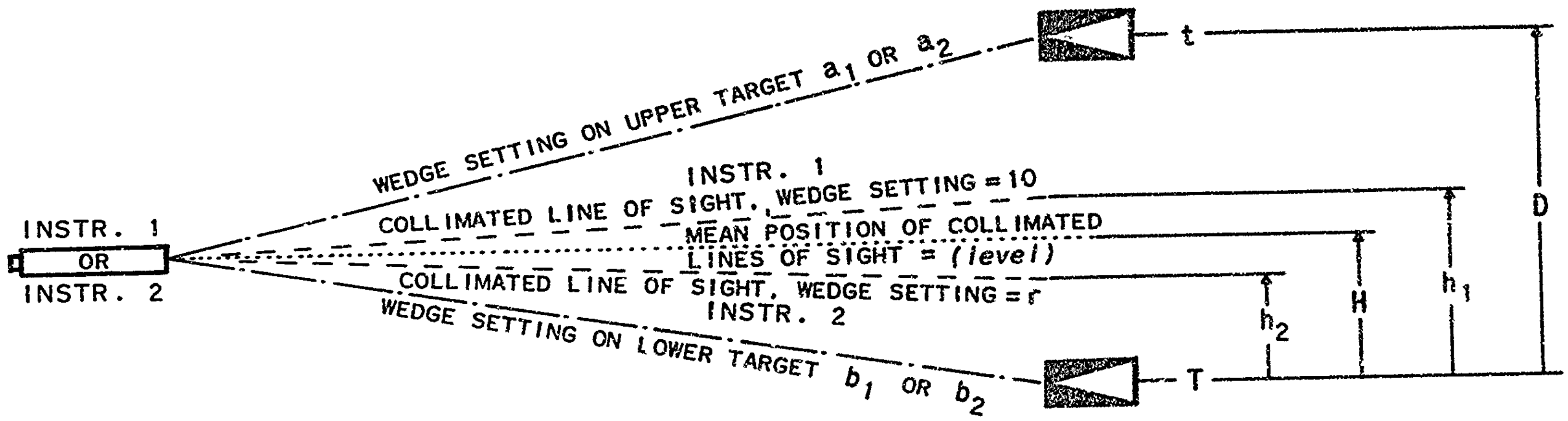
o. Make new setting in counterclockwise direction by repeating steps (k), (l), and (m). Record reading.

p. Repeat steps (n) and (o), in sequence, until a total of ten settings has been made (and recorded) with Instr. No. 1, on the upper target. (The mean of these ten readings is the quantity "a_1".)

q. Repeat sequence of (a) through (h) with Instr. No. 2 until a series of ten settings, in counterclockwise-clockwise sequence has been made on the lower target. (The mean of these ten readings is the quantity "b_2".)

r. Repeat sequence of (i) through (p), with Instr. No. 2 until a series of ten settings, in clockwise-counterclockwise sequence, has been made on the upper target. (The mean of these ten readings is the quantity "a_2".)

The above series of operations (a) through (r), preceded by a Releveling (par. 27) and a Reciprocal Collimation setting (par. 25), constitutes a "Set" of observations. The relationships of the observed quantities are shown in Fig.11. Four such sets of observations shall be made to constitute a "series".



$$h_1 = (D)\frac{b_1 - 10}{b_1 - a_1} \qquad h_2 = (D)\frac{b_2 - r}{b_2 - a_2} \qquad H = (h_1 + h_2)/2$$

WEDGE SETTINGS ON TARGETS

Figure II

Each set must be preceded by a Releveling (par. 27) and a Reciprocal Collimation setting (par. 25). It is emphasized that, as stated in par. 27, in the Releveling operation, in successive sets, the telescopes of both instruments must be alternately pointed toward (↑) and away (↓) from the Target Station. These positions are indicated, for a reminder, on the field note form. In every case, the circular bubble shall first be displaced (decentered) toward the Target Station.

30. COORDINATION, Reciprocal Observations:

As stated in par. 20, simultaneous reciprocal observations should be made with a second complete set of Valley Crossing Equipment over an adjacent course, referring to the same bench marks if practicable. Each set of observations should be started at the same time with each outfit, with starting time coordinated by radio.

31. RELEVEL and RECIPROCAL COLLIMATION, Final:

After completion of the fourth set of Target Observations (par. 29), the Releveling operation (par. 27) is repeated, with the telescopes pointed toward (↑) the Target Station, followed by a Reciprocal Collimation (par. 25).

32. BENCH MARK, Final Observation:

After the final Releveling and Reciprocal Collimation, the observations of a series are concluded by repeating the readings on a precise level rod held on the adjacent bench mark, as outlined and described in par. 26. The number of series to be observed depends on the length of the crossing and will be stated

in the specific project instructions. The settings must be made on the same rod graduations set on in the initial bench mark observations (par. 26).

33. METEOROLOGICAL OBSERVATIONS:

Since the refractive index of air is a function of air density which, in turn, varies with barometric pressure and temperature, it might be helpful in evaluating results to have values of these quantities. Therefore, at each Reciprocal Collimation, except the first, barometric pressure and air temperature shall be observed and recorded. These quantities are not used in the field computations, but will be considered during evaluation and adjustment in the office.

COMPUTATION

34. RECORDING:

Recording of all observations shall be made on the form entitled "VALLEY CROSSING NOTES". A specially annotated copy has been prepared (Fig. 12) with explanatory notes which, together with these instructions, should suffice.

35. HEIGHT OF INSTRUMENT ABOVE LOWER TARGET:

Each "set" of observations provides a determination of the mean height of the two levels at the Instrument Station above the lower target at the Target Station, which is the quantity designated "H". This meaning process eliminates the effect of any slight difference in elevation between the two levels as mounted on the Base Plate as well as providing a result that is, because

VALLEY CROSSING NOTES

TARGET POSITIONS ON COLUMN: Upper (t) = scm Lower (T) = scm D = scm

		INSTRUMENT No. 1						INSTRUMENT No. 2						V. C. SET			
	↓	RECIPROCAL COLLIMATION									1	2	r	COMPUTATIONS			
BM	ROD	LOWER	G		1	2	ℓ_1	LOWER	G		1	2	ℓ_2	ℓ_1-10	ℓ_1-u_1	i_1	I
		UPPER	g		1	2	u_1	UPPER	g		1	2	u_2	ℓ_2-r	ℓ_2-u_2	i_2	S
	↑	RECIPROCAL COLLIMATION									1	2	r_{BEFORE}	BAROM	TEMP		
SET 1	TARGET	1	3	5	7	9	LOWER	1	3	5	7	9	LOWER	b_1-10			
		2	4	6	8	10	b_1	2	4	6	8	10	b_2	b_1-a_1	h_1		
		1	3	5	7	9	10.00	1	3	5	7	9	r_{MEAN}	b_2-r		H	S
		2	4	6	8	10	a_1 UPPER	2	4	6	8	10	a_2 UPPER	b_2-a_2	h_2		
	↓	RECIPROCAL COLLIMATION									1	2	r_{AFTER}	BAROM	TEMP		
SET 2	TARGET	10 WEDGE SCALE SETTINGS, LOWER TARGET, INSTR. 1			10 WEDGE SCALE SETTINGS, UPPER TARGET, INSTR. 1		LOWER	10 WEDGE SCALE SETTINGS, LOWER TARGET, INSTR. 2			10 WEDGE SCALE SETTINGS, UPPER TARGET, INSTR. 2		LOWER				
							10.00										
							UPPER						UPPER				
	↑	RECIPROCAL COLLIMATION												BAROM	TEMP		
SET 3	TARGET						LOWER						LOWER				
							10.00										
							UPPER						UPPER				
	↓	RECIPROCAL COLLIMATION												BAROM	TEMP		
SET 4	TARGET						LOWER						LOWER				
							10.00										
							UPPER						UPPER				
	↑	RECIPROCAL COLLIMATION												BAROM	TEMP		
BM	ROD	LOWER						LOWER									
		UPPER						UPPER									

LOCATION .... FIELD PARTY .... WEATHER ....

REMARKS *FIELD NOTES FORM - Annotated copy showing entry locations of field data and computed quantities* .... DATE ....

Figure 12

of the Reciprocal Collimation process (par. 25), compensated for the effects of vertical collimation error in the instruments. This determination is, however, subject to the effects of refraction and earth curvature (par. 20), but these effects are compensated by observing a similar height difference with a second set of equipment, simultaneously, but in the opposite direction (par. 30). In taking the mean of two such simultaneous sets, the curvature and refraction effects, being of opposite algebraic sign, will be compensating.

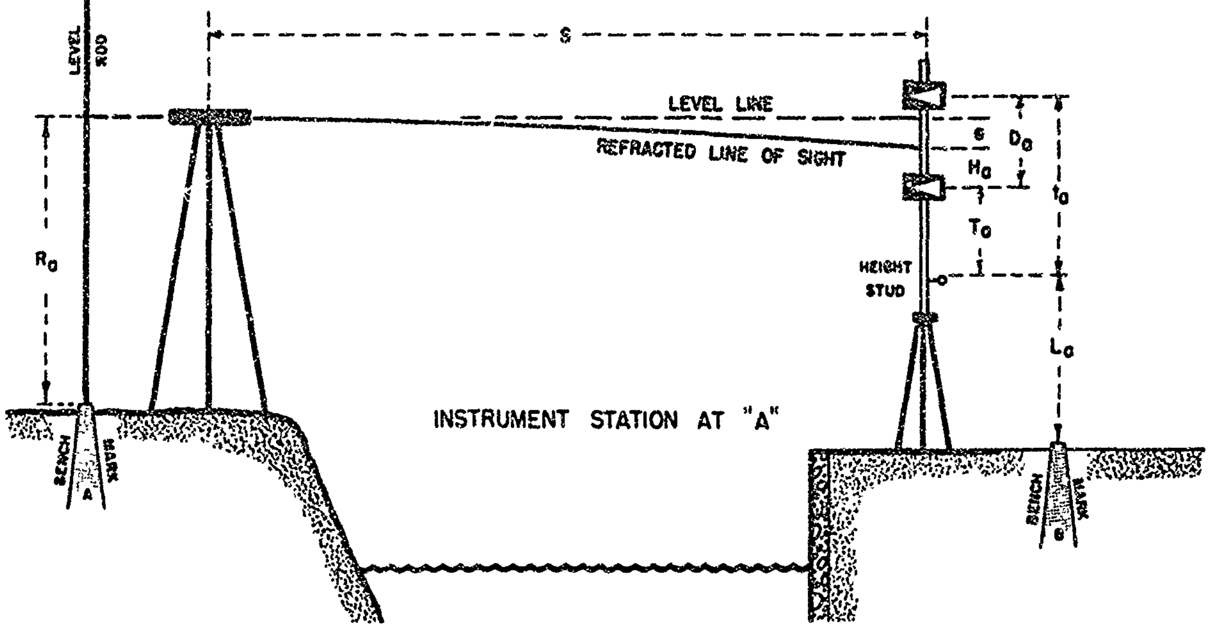
36. GEOMETRICAL RELATIONSHIPS:

Figure 13 shows the geometrical relationships of the various observed and computed quantities involved in a set of simultaneous reciprocal observations (par. 30). The difference of elevation is determined from Bench Mark "A" to Bench Mark "B" in both indicated situations, but in Measurement "a" the Instrument Station is adjacent to Bench Mark "A" while, in Measurement "b", a reciprocal observation is made with the Instrument Station adjacent to Bench Mark "B". The various corresponding quantities in both situations are indicated with common notations, but subscripted "a" or "b" for the appropriate observation. For the sake of clarity, in each situation a single instrument is symbolized, but this is intended to indicate the mean situation of a pair of instruments in a typical Instrument Station set-up (pars. 8, 9, and 16).

37. NOTATION:

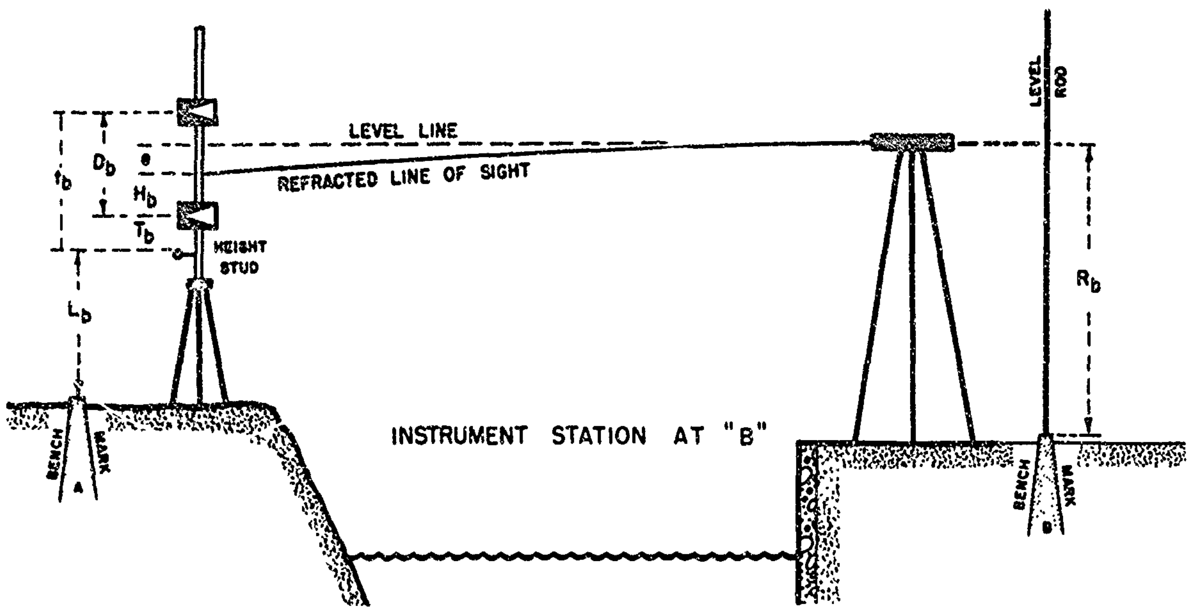
The notation to indicate the various observed and computed quantities is as follows (subscripts "1" and "2" are used in the

VALLEY CROSSING MEASUREMENTS



MEASUREMENT "a" FROM A TO B

DIFFERENCE ELEVATION $= \Delta_a = R_a - e - [H_a + (T_a + L_a)]$



MEASUREMENT "b" FROM A TO B

DIFFERENCE ELEVATION $= \Delta b = [H_b + (T_b + L_b)] + e - R_b$

FIGURE 13

text to denote quantities applicable to Instr. No. 1 or Instr. No. 2):

b = Mean of 10 wedge scale readings of level when set on lower target (par. 29, a-h or q). Units are graduations of the wedge scale (par. 5).

a = Mean of 10 wedge scale readings of level when set on upper target (par. 29, i-p or r). Units as in "b" above.

r = Mean of Reciprocal Collimation readings on Instr. No. 2 (par. 25), mean of two readings (one clockwise and one counter-clockwise) <u>before</u>, and two more readings <u>after</u> a <u>set</u> (par. 29, following item "r") of readings on lower and upper targets ("b" and "a", above, with Instr. No. 1 and Instr. No. 2). Units are graduations of the wedge scale. Take note that the comparable reading of Instr. No. 1 is <u>always</u> <u>set</u> to 10.00. (par. 25, b), so there is no need to subscript "r".

h = Intercept of collimated line of sight of an instrument, above Lower Target; a computed quantity. Subscripted 1 or 2. Semi-centimeter units.

ℓ = Mean of two wedge scale readings of level when set on lower graduation ("G") of level rod held on bench mark adjacent to Instrument Station (par. 26, i and j). Units are graduations of the wedge scale.

u = Mean of two wedge scale readings of level when set on upper graduation ("g") of level rod held on bench mark adjacent to Instrument Station (par. 26, i and j). Units are graduations of the wedge scale.

i = Intercept of collimated line of sight of an instrument, above the lower rod graduation ("G") on which wedge settings " ℓ " were made (semi-centimeters).

Following quantities are not subscripted to identify an individual instrument, but may be subscripted "a" or "b" to identify the corresponding separate quantities obtained from a pair of simultaneous reciprocal observations (par. 30, 36, and Fig. 13):

T = Position of lower target above Height Stud on Target Column (pars. 11 and 21d). Units are semi-centimeters; 0, 40, or 80.

t = Position of upper target above Height Stud on Target Column (pars. 11 and 21d). Units are semi-centimeters; 40, 80, or 120.

D = Interval between centers of upper and lower target.
= t-T (semi-centimeters)

H = Intercept of mean of collimated lines of sight of Instr. Nos. 1 and 2, above the Lower Target. It is the mean of h_1 and h_2 for any given set (par. 35).

I = Intercept of mean of collimated lines of sight of Instr. Nos. 1 and 2, above the lower sighted graduation. It is the mean of i_1 and i_2 for any set of pointings on the level rod held on the bench mark adjacent to the Instrument Station (par. 26).

R = Intercept of mean collimated lines of sight of Instr. Nos. 1 and 2, on a level rod held on the bench mark adjacent to the Instrument Station (par. 26).

L = Difference of elevation between bench mark adjacent to Target Station and the Height Stud on the Target Column, determined by standard precise level techniques (par. 21e).

G = Value of lower graduation (semi-centimeters) of level rod (held on bench mark adjacent to Instrument Station) on which wedge settings ("ℓ", par. 26, e and j) are made.

g = Value of upper graduation (semi-centimeters) of level rod (held on bench mark adjacent to Instrument Station) on which wedge settings ("u", par. 26, i and j) are made.

d = Interval between graduations of level rod on which wedge settings are made.

= g-G (semi-centimeters).

38. COMPUTATION OF ROD INTERCEPT ("R")

As shown in Fig. 13, the Rod Intercept is the mean height of the two levels (Nos. 1 and 2) above the bench mark adjacent to the Instrument Station. It is obtained from the observations described in par. 26.

First compute i_1 and i_2 for the beginning observations:

$$i_1 = (d)\,\frac{\ell_1 - 10}{\ell_1 - u_1}$$

$$i_2 = (d)\,\frac{\ell_2 - r}{\ell_2 - u_2}$$

(r is the mean reciprocal collimation setting made with Instr. No. 2 before pointing on the level rod)

Then compute the mean:

$$I = \frac{i_1 + i_2}{2}$$

Then:

$$R = G + I \qquad \text{(starting value)}$$

Then:

Repeat above computation using data obtained from the final observations on the level rod held on the adjacent bench mark. This should agree with the first value of "R" within about 0.3 semi-centimeter.

The mean of the two values of "R" (starting and final) should be used for the series of observations.

39. COMPUTATION OF TARGET INTERCEPT ("H")

As shown in Fig. 13, the Target Intercept is the mean height of the intercepts of the collimated lines of sight of the two levels (Nos. 1 and 2) above the Lower Target. It is obtained from the observations described in par. 29.

First compute h_1 and h_2 for the first set of observations:

$$h_1 = (D) \frac{b_1 - 10}{b_1 - a_1}$$

$$h_2 = (D) \frac{b_2 - r}{b_2 - a_2}$$

(r is the mean of four reciprocal collimation settings made with Instr. No. 2, two <u>before</u> the set of readings on the targets and two <u>after</u> the set of target readings)

Then compute the mean:

$$H = \frac{h_1 + h_2}{2}$$

40. COMPUTATION OF HEIGHT OF TARGET INTERCEPT ABOVE ADJACENT BENCH MARK ("Z")

As is obvious from Fig. 13, the height of the Target Intercept above the adjacent bench mark is equal to the difference in elevation between the bench mark and the Height Stud ("L", par. 21e) plus the height of the Lower Target above the Height Stud ("T", par. 21d) plus the Target Intercept ("H", par. 39) thus:

$$Z = H + T + L \qquad \text{(semi-centimeters)}$$

This difference is subject to the error caused by refraction and earth curvature ("e").

41. DIFFERENCE IN ELEVATION:

Still referring to Fig. 13, it can be seen that the difference in elevation between two bench marks, as from "A" to "B", computed from the data obtained with the Instrument Station adjacent to "A" is:

$$\Delta_a = R_a - e - (H_a + T_a + L_a)$$

Considering a set of reciprocal observations made simultaneously with the Instrument Station adjacent to "B"; the difference in elevation from "A" to "B" (in the same sense of direction as above) is:

$$\Delta_b = (H_b + T_b + L_b) + e - R_b$$

"e" is assumed to be the same for each one of the simultaneous reciprocal observations. Hence, taking the mean:

$$\Delta_{mean} = \frac{\Delta_a + \Delta_b}{2} = 1/2\ (R_a - e - Z_a + Z_b + e - R_b)$$

Since the "e" is the same, the effect is cancelled, and

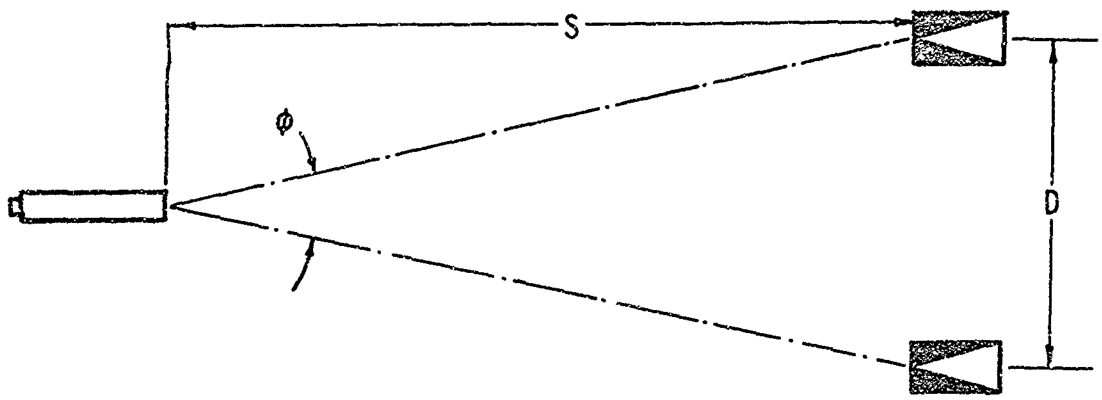
$$\Delta_{a,b} = 1/2 \quad (Ra - Za) + (Z_b - R_b)$$

A difference in elevation (observe the "from-to" sense carefully) can be computed thus from each pair of simultaneous reciprocal observations (semi-centimeter units)

No attempt should be made to evaluate the accuracy of the results obtained by comparing (R_a - Za) with (Zb - Rb). These quantities are affected by the unknown value of "e", and are not supposed to be equal. The only way to evaluate the results is to compare the values of the mean differences obtained from several sets.

42. COMPUTATION OF DISTANCE ("S"):

The assumption that the values of "e" from the two observations in a simultaneous set are equal is based on the assumption that the distance from Instrument to Target is the same with both sets of equipment. The set-ups should be made so as to effect this condition but a check may be made by using the Target set as a vertical subtense bar, using the wedge-scale readings as an accurate reading of the vertical angle subtended by the target pair, whose vertical spacing is accurately known. Considering the approximate sketch on the following page.



To a sufficient approximation:

$$S = D/\phi \qquad (\phi \text{ is small angle})$$

when D and S are in the same units and ϕ is in radians.

On the Zeiss V. C. apparatus, the angle (b - a) is in wedge-scale units, 1 unit - 20 seconds = $1 \cdot 10^{-4}$ radian (to a sufficient approximation)

D is in semi-centimeters, or:

$$D \text{ (meters)} = D \text{ (semi-centimeters) } /200$$
$$= \frac{D}{2} \text{ (semi-centimeters) } .10^{-2}$$

Hence:

$$S \text{ (meters)} = \frac{1/2D \cdot 10^{-2}}{\phi \cdot 10^{-4}}$$
$$= \frac{50D}{\phi}$$

The "D" is as defined in par. 37 (the target spacing).

"ϕ" is the appropriate value, mean of $(b_1 - a_1)$ and $(b_2 - a_2)$

43. ACCURACY ATTAINABLE:

The accuracy obtainable with the V. C. apparatus seems to be routinely compatible with that attainable by the conventional balanced-sight techniques used with the plane-parallel plate micrometer and precise level rods, that is:

$$1.5 \text{ mm} \quad \sqrt{K} \qquad \text{(K is length of water crossing in kilometers)}$$

This accuracy, however, can be attained only by strict observance of all the detailed routines outlined herein. Furthermore, all settings on targets, reciprocal collimations, etc. must be made with the utmost care, similar to that required for pointings and micrometer readings made with a first-order theodolite. Any less care will vitiate the process and negate the fine design of this equipment.

SUMMARY

44. SUMMARY OF OBSERVATIONAL PROCEDURES:

On the following page is a summary "check-list" of the process of making a series of water crossing observations.

CHECK LIST OF WATER CROSSING PROCEDURES

PRELIMINARY

1. Reconnoiter for sites.
2. Establish bench mark adjacent to each instrument set-up.
3. Set up instruments.
4. Adjust target settings on column.
5. Run closed set of level on each side, between bench mark and height stud on target.

OBSERVATIONS (each side)

1. Set levels on base plate. Set leveling screws to mid-range positions.
2. Point both instruments away (↓) from opposite station. Level. Set infinity focus. Set reciprocal collimation (2 settings at Instr. No. 2)
3. Point on two graduations, with each instrument, on level rod held on bench mark (2 settings, each instrument on each graduation)
4. Point both instruments toward (↑) opposite station, Delevel and relevel. Set infinity focus. Set reciprocal collimation.
5. Make "set" of observations on targets on opposite shore:

   a. 10 pointings, Instrument No. 1, upper target
   b. 10 pointings, Instrument No. 1, lower target
   c. 10 pointings, Instrument No. 2, upper target
   d. 10 pointings, Instrument No. 2, lower target

6. Point both instruments away (↓) from opposite station. Delevel and relevel. Set infinity focus. Set reciprocal collimation.
7. Make second set of target pointings as in (5).
8. Point both instruments toward (↑) opposite station. Delevel and relevel. Set infinity focus. Set reciprocal collimation.
9. Make third set of target pointings as in (5).

10. Point both instruments away (↓) from opposite station. Delevel and relevel. Set reciprocal collimation.

11. Make fourth set of target pointings as in (5).

12. Point both instruments toward (↑) opposite station. Delevel and relevel. Set reciprocal collimation.

13. Make another set of pointings on level rod held on adjacent bench mark as in (3).

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Department of the Army Lake Survey District, Corps of Engineers	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP
3. REPORT TITLE The Zeiss Apparatus for Crossing Water Spans in Precise Leveling	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report	
5. AUTHOR(S) (First name, middle initial, last name) Ralph Moore Berry	
6. REPORT DATE October 1969	7a. TOTAL NO. OF PAGES 60 — 7b. NO. OF REFS 5
8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) Miscellaneous Paper 69-6
b. PROJECT NO c. d.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
10. DISTRIBUTION STATEMENT Distribution of this document in unlimited.	
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

One of the serious problems encountered in precise leveling is the crossing of water spans which are wider than the maximum sight-distance specified for the order of accuracy desired. This problem is met with some variation of a "water-crossing" technique which usually involves the two following principles:

a. Reciprocal observations, and

b. Controlled tilting of the line of sight.

The Zeiss "Valley-Crossing" Equipment is a set of accessories for the Zeiss Ni2 "automatic" level, by means of which the controlled tilting of the line of sight (b above) can be accomplished quickly and accurately. The tilting is effected through a rotating prism set in front of the objective with the amount of rotation being indicated by an integral optical scale. Simultaneous use of two instruments on the same tripod-mount permits calibration of the rotating scale by frequent reciprocal collimation settings. The reciprocal, or simultaneous, observations (a above) are accomplished with another set (two) of instruments, similarly equipped, on the opposite shore. Thus, a total of four levels is required for the proper accomplishment of the operation.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

Unclassified
Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Vertical Control						
Leveling						
Precise leveling instrumentation						
Great Lakes						
Surveying						
Water Crossing						
Geodesy						

Instrumentation to accomplish the measurement is described.

Unclassified
Security Classification